ENGINEERED BARRIER ENVIRONMENT, YUCCA MOUNTAIN*

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INTRODUCTION:

The US Department of Energy is studying the suitability of Yucca Mountain (YM) as a potential nuclear waste repository site. Environmental conditions are important to engineered barrier system (EBS) design, materials testing, selection, design criteria, waste-form characterization, and performance assessment. Yucca Mountain is located in uninhabited desert which results in an environmental framework (unsaturated conditions, and sorptive properties of the rock materials) that is generally favorable for waste disposal. However, waste package (WP) and engineered barrier system (EBS) design concepts, including materials testing and selection, design criteria development, waste-form characterization, and performance assessments all require a specific and detailed understanding of the environmental conditions that will interact with the WP/EBS. Environmental conditions assessments from a series of laboratory and modeling studies have been compiled into a summary report called *Preliminary Near-Field Environment Report (NFER)*.[1] These studies provide the current understanding of the near-field environmental conditions at YM that not only exist now but will exist in the future. Because the environmental conditions can change with time, emphasis of the investigations were on processes and changed (not ambient) conditions.

Quantitative analyses of the actual NFE must incorporate information from EBS and repository design, operational practices and sequences, and performance assessments into environmental assessment models. Also, the NFE depends on many processes and design details that are not determined at this time. Therefore, the emphasis of the studies and this report is on processes and changed (not ambient) conditions resulting from interaction with waste. Thus, the environmental descriptions in this report and in the NFER should be viewed as preliminary.

DISCUSSION:

The potential repository is located in a 500 to 750 m thick unsaturated zone, in the Topopah Spring Member of the Paintbrush tuff (Tpt). Infiltration is expected to be low with maximum flux estimated from 0.05 to 1.0 mm/yr. The unsaturated rock has a significant suction potential, with a measurable hysteresis between drying and wetting. Measured saturated water permeability of intact Topopah Spring tuff sample at room temperature is about 0.3 μD. Saturated water permeability of fractured Topopah Spring tuff is at least three orders of magnitude greater than that of intact tuff, ranging from 0.85 to 13 mD.

Waste emplacement will elevate rock mass temperatures, possibly above the boiling point which would result in (1) a dry-steam environment during periods when the temperatures remain above the boiling point, and (2) dried-out rock mass (lower degree of saturation) that will inhibit flow of liquid water, thus minimizing water contact with the EBS. Emplacement of older fuel at higher APDs will greatly increase the drying and duration of heat effects. Calculations show that waste placed with greater than 40 kW/acre density will result in significant dry-out. Dry steam conditions can persist for more than 4000 yr at the repository edge or over 10,000 yr for the center of the repository, and will persist for thousands of years for all APDs above 57 kW/acre.

Except for gaseous radionuclides, the most likely transport mechanism for radionuclides involves aqueous corrosion and flow mechanisms. Fracture dominated flow, under transient conditions and out of capillary equilibrium with the matrix, is the most likely way for water to contact waste.

The most significant source of water contacting the WPs is condensate. For a significant portion of the dry out period, there will be preferential drainage away from the WP emplacement holes and drifts. Experiments in G-Tunnel have shown that a considerable portion of the condensate drains down fractures so that large volumes of condensate cannot collect above the WPs. Even if water collected, it would not unlikely be able to contact WPs. As rock cooled, water would flow preferentially down fractures in mid pillar regions where the boiling point isotherm retreat would be greatest. Since it would take hundreds to thousands of years for the temperatures to drop below boiling, there would be sufficient time for any water that did not drain through pillar areas to be imbibed into the dried-out matrix.

Radiation effects are functions of the radiation dosage and the moisture/vapor/rock composition. Effects are not expected to extend beyond 1 to 2 cm into the rock mass. Radiation is expected to have negligible effects on the geomechanical behavior. Radiation shielding or other design considerations can effectively eliminate the effects of radiation on the NFE.

The intact rock is quite strong with a uniaxial strength of 155 MPa ($\pm$ 59 MPa) and a high Young's modulus. Thermal loading will alter the stress in the rock near the emplacement openings as a function of time. Analyses indicate that the boreholes should be stable and that stresses may remain at levels in the range of 20 to 40 MPa for well over 100 yr.

CONCLUSIONS:

Unsaturated conditions at Yucca Mountain should result in limited liquid water contact with waste packages (WP), and thus minimized container corrosion, waste-form leaching, and radionuclide transport mechanisms. Both aqueous and gaseous release pathways will likely be dominated by the fracture network system rather than the matrix pore interconnections.

Post-emplacement conditions will be influenced by emplacement of the waste and closure of the repository. Interactions between the EBS and the NFE are influenced by the thermal regime that results from waste emplacement. Temperatures, depending on mass loading of the waste, vary from around boiling to about 200°C. Temperatures that exceed the boiling point result in: (1) a dry-steam environment around the waste during periods when the temperatures remain above the boiling point, and (2) dried-out rock mass (lower degree of saturation) that will inhibit flow of liquid water through the dried rock thus minimizing water contact with the EBS.

Durations of rock mass temperatures above the boiling point may be extended to thousands or even tens of thousands of years depending on the designs chosen. The period during which the rock remains dry is much longer than the period of elevated temperatures. Conservative analyses (ignoring condensate drainage) indicate that, for high APDs, the system may not return to ambient saturation conditions for 100,000 to 200,000 years. If the effects of condensate drainage are considered, the time for saturation to return to ambient would be even longer than indicated.

Chemical changes may result from increased temperatures and may result in permanent changes in hydrologic properties. Also, fracture healing may result from mineral dissolution/deposition associated with heating/drying processes. However, these changes are dominated by aqueous processes, and once rock/water temperatures exceed the boiling point, so that the rock dries, these aqueous processes cease. It is unknown if fracture healing might be significant.

One of the unexpected benefits of high mass loading results from the fact that the WP environment, once dried, will remain dry long after the temperatures have dropped below boiling. Because the dryout front moves fairly rapidly for the first five years and then slows considerably, the time of contact may not be sufficient for aqueous processes to go to completion in the near-field. Once dried they will be stopped until the water returns. By the time the water returns the temperatures will have dropped so that there will not be the accelerated geochemical processes. In contrast, if a cooler emplacement scenario is followed where the temperatures are elevated but not above boiling then the water remains in the system at elevated temperatures so that geochemical processes can likely go to completion.

References

1. D.G. WILDER, Scientific Editor, "Preliminary Near Field Environment Characterization Report, Vol I, and Vol II", UCRL-LR-107476, Lawrence Livermore National Laboratory, Livermore, CA (1992),

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